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Pre-landfall evacuee perception of the meteorological hazards associated with Hurricane Gustav

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Abstract In this study, evacuees from the path of Hurricane Gustav were surveyed to determine which meteorological hazards most influenced their decision to leave. Surveys were conducted along two major evacuation routes on August 30 and 31, 2008, to collect time-sensitive data on individual evacuation decisions related to the meteorological hazards from Hurricane Gustav. The regions of New Orleans, Houma, and Lafayette were represented most frequently, as determined by zip code data collected from the surveys. Responses were evaluated first by meteorological hazard for the entire dataset and then by three-digit zip code region. Overall, storm surge was the most important meteorological variable, followed by the size of the storm, wind, rain, and tornadoes. When separated into three-digit zip code regions, analyses revealed evacuees from in and around New Orleans were driven to evacuate as a result of the perceived threat from storm surge and storm size; residents in the Houma, Louisiana region were motivated to leave due to the threat from storm surge; and Lafayette and the surrounding areas were most-concerned with the threats posed by hurricane-force winds. Given the forecast track and intensity, survey respondents understood the meteorological hazards from Gustav and were motivated to leave based on personal evaluations of risk associated with the storm.

Keywords Hurricane · Evacuation · Meteorological hazards · Perception · Landfall

1 Introduction

The process of providing accurate, timely information about potential land-falling hurricanes has changed dramatically over the past three decades. Previously, information was funneled through television and radio outlets, which were then charged with disseminating vital updates to the general public. Evacuation was a response in real time to changes in characteristics, conditions, and forecasts of the oncoming storm. More recently, pertinent

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storm information became easier to access with the advent of the internet, cable and satellite television, and cellular phones, making personal evacuation decisions increasingly more popular when compared to official government-issued orders (Gladwin et al. 2009). There is a large cross-section of research published on various aspects of evacuation activity based on personal choices, such as shadow evacuations (Baker 2000), evacuation timing (Dow and Cutter 2002), social variables (Baker 1991), and pets (Whitehead et al. 2000). An area that has yet to receive considerable focus, however, is how evacuation decisions are related to the meteorological hazards of the hurricane.

Evacuees in the projected path of a hurricane are faced with numerous decisions in the time prior to landfall, with their decisions often based on recent landfall experiences (Baker 1991) when assessing the severity of the up-coming hurricane threat (Zhang et al. 2007). Often, a person with previous hurricane experience will ask questions about how the current storm's meteorological characteristics compare with past storms. Questions about surge potential, the amount of rain, and the strength of the wind gusts are all evaluated relative to the projected path of the storm address specific hazards related to the storm, which varies by location according to the perceived vulnerability of each location. It is imperative, therefore, to understand which storm hazards are most-concerning to potential evacuees, how these concerns vary spatially by location, and how these concerns may influence their decision to evacuate.

The first objective of this research is to determine which storm hazards elicit the greatest concern for residents of southern and coastal Louisiana. Storm hazards were separated into four meteorological variables: storm surge, rainfall, wind, and tornadoes. A fifth non-meteorological variable termed "storm size" was also included since the size of the storm influences the number of people affected as well as the duration of the previously mentioned meteorological variables. The second objective is to assess which storm hazards were viewed as a more significant threat to each of the three-digit zip codes regions represented. Results were tested for statistically significant differences in the meteorological threats posed by storm surge, rainfall, wind, tornadoes, and the size of the storm between the New Orleans, Houma, and Lafayette zip code regions. As this is the first known attempt at analyzing threat by isolating storm hazards during the evacuation process, results are discussed in the context of an experienced hurricane population in southern and coastal Louisiana (Keim et al. 2007).

2 Relevant literature

Research on hurricane-related evacuation behavior and response has long received attention. Beginning in the 1950s, researchers began to document the response of coastal residents to hurricane threats (e.g., Killian 1954). In the following decades, more attention was placed on the response of evacuees from land-falling hurricanes and the demographics of both evacuating and non-evacuating populations (Moore et al. 1963; Wilkinson et al. 1970; Baker 1980, 1986, 1990). These studies focused on individual action relative to the hurricane and the potential impact other variables might have that could be used as future predictors of evacuation behavior. In a majority of these studies, it was noted that response to hurricane threats was influenced by a number of social, environmental, and physical factors that produced geographically distinct reactions (Gladwin and Peacock 1997; Whitehead et al. 2000; Lindell et al. 2005).

Following early empirical studies, interest developed in understanding hurricane evacuation behavior based on the perceived risk of the storm. Burton et al. (1978) and Dash

and Gladwin (2007) noted the underlying issues associated with understanding the evacuation decision process are typically complex and rely on a number of personal factors that are difficult to categorize. In post-hurricane surveys, researchers found a variety of factors that influenced evacuees' decisions to leave. Examples of these decisions were based on the threat of personal injury (Dash and Gladwin 2007), differences between genders assessing hurricane threats (Bateman and Edwards 2002), in previous experiences with hits or misses from hurricanes (Baker 1979; Dow and Cutter 1998), or a result of various socioeconomic and personal factors (Baker 1991; Wilmot and Mei 2004; Lindell et al. 2005; Kusenbach et al. 2009). Ultimately, decisions to evacuate hinge on personal assessment of risk based on an individual's interpretation of a myriad of factors associated directly or indirectly with the hurricane.

More recently, Hurricane Rita provided an opportunity for another evaluation of evacuation motivation. Zhang et al. (2007) surveyed 120 evacuees from the Texas Gulf Coast who were in the path of Rita. Similar to previous studies, they administered a post-event survey 6 months after Rita's landfall to better understand the perceptions of risk associated with the storm. Unique to this study was their explicit examination of the respondent's perception of risk relative to four hurricane-related meteorological threats, which included storm surge, wind, flooding, and tornadoes. Their study noted that there were storm variables that were of greater concern than others; however, when analyzed in more detail, the four threats were not significantly different. Other studies have addressed concerns related to the meteorological variables of the hurricane; however, they were couched in broader issues of how risk was evaluated by gender (e.g., Bateman and Edwards 2002). These results highlight the importance of understanding factors people consider when making their evacuation decision, including the physical characteristics of the storm and the specific, hurricane-related meteorological hazards.

Zhang et al. (2007) as well as Dash and Gladwin (2007) note additional issues that must be resolved to more accurately represent the mindset of the evacuee. Specifically, they note that in the months following landfall, evacuees may have difficulty recalling the events and situations that ultimately lead to their decision to leave. For example, evacuees may return to more or less damage relative to what they anticipated before leaving, influencing their post-hurricane reflection and possibly leading to inaccurate accounts during recall. To address this issue, Dash and Gladwin (2007) call for more pre-event research to better understand the factors that ultimately trigger a personal evacuation decision. This study attempts to address two areas where data collection and analyses have been limited: understanding the meteorological hazards of the hurricane that may have influenced evacuation decisions and surveying evacuees prior to or during the evacuation.

3 Data collection, methods, and study area

3.1 Data collection and methods

A team of seven researchers was assembled from the University of Alabama (UA) and Mississippi State University (MSU), which included three faculty (two from UA, one from MSU), two graduate students (both from MSU), and two undergraduate students (both from UA). All members of the survey team had previous experience with survey data collection and were certified by each university's Institutional Review Board. The group was kept small to ensure more efficient mobility during the survey process (two vehicles were used) and to simplify potential logistical issues as Gustav approached. The group

departed from Tuscaloosa, Alabama around 15:00 UTC on the morning of August 30, 2008. At the time of departure, there was no hurricane watch or warning issued for the Gulf Coast region. In the days preceding departure, there were a number of high-traffic locations the team considered to administer the survey, including rest stops, gas stations, restaurants, and hotels; generally, areas where large evacuee populations were anticipated. Previous studies had noted large numbers of evacuees in areas along the evacuation routes in these areas due to congested roadways and limited or inadequate access to food, fuel, and hotel rooms (Zhang et al. 2007).

The survey team arrived in southern Mississippi at approximately 20:00 UTC on August 30 and began the initial survey process. After attempting to survey evacuees at a number of possible locations listed earlier, rest stops were chosen as the preferred location to conduct the surveys due to the ease of access, the high volume of evacuee traffic, and the willingness of the evacuees to participate. Evacuees noted that the slow pace of traffic and the time they had spent in their vehicles had prompted their detour into the rest stop. We acknowledge that collecting survey responses from evacuees at rest stops requires a certain level of mobility and access to the necessary means for travel that may not be completely representative of the larger population of the region. However, given the small window of time prior to landfall, the survey data collected from the independently mobile population of southern and coastal Louisiana were considered to be representative of the larger population.

The first survey location was along Interstate 59 in southwestern Mississippi, near Picayune, Mississippi (Fig. 1). After receiving permission from the rest stop facility manager, researchers surveyed 75 evacuees who were primarily from the New Orleans metropolitan area from approximately 20:00–23:00 UTC. Traffic volume through the rest stop during survey collection averaged approximately 60 vehicles per hour. While the surveys were being administered at the Interstate 59 rest stop, the National Hurricane Center issued the first hurricane watch at 21:00 UTC for the northern Gulf Coast. As sunset approached, survey collection stopped and the research team moved west to the Interstate 49 corridor to prepare to survey evacuees of central and southern coastal Louisiana the next day. At 09:00 UTC on August 31, the National Hurricane Center upgraded the northern Gulf Coast, including all of coastal Louisiana, to a hurricane warning. At approximately the same time, the state of Louisiana activated the contraflow evacuation routes throughout the state. As a result, Interstate 49 was converted into four vehicle lanes of north-bound traffic to facilitate faster evacuation of the parishes south of Interstate 10 (the major east–west thoroughfare in the region). The survey team positioned themselves at a rest stop along Interstate 49 near Opelousas, Louisiana, where 200 surveys were completed. Permission to survey evacuees at the Interstate 49 rest stop was given by the rest stop manager. The volume of traffic at the Interstate 49 rest stop was considerably greater than at the Interstate 59 rest stop the previous day, with an average of roughly 150 vehicles per hour during the 3-h survey period from 14:00 UTC to 17:00 UTC (Fig. 2). A majority of the evacuees using the Interstate 49 contraflow evacuation route through central Louisiana were from the Lafayette and Houma areas, with residents of the western suburbs of New Orleans represented as well. During the 2-day survey period, evacuees represented those participating in both voluntary and mandatory evacuation orders, depending on location.

At each rest stop, evacuees were surveyed using a convenience sampling method. This method was employed due to the time-sensitive nature of data collection, the exploratory nature of the analysis, and to survey as many evacuees as possible. Henderson et al. (2009) noted the utility of employing convenience sampling when they used this method to query displaced residents in the aftermath of Hurricane Katrina. Using this sampling method,

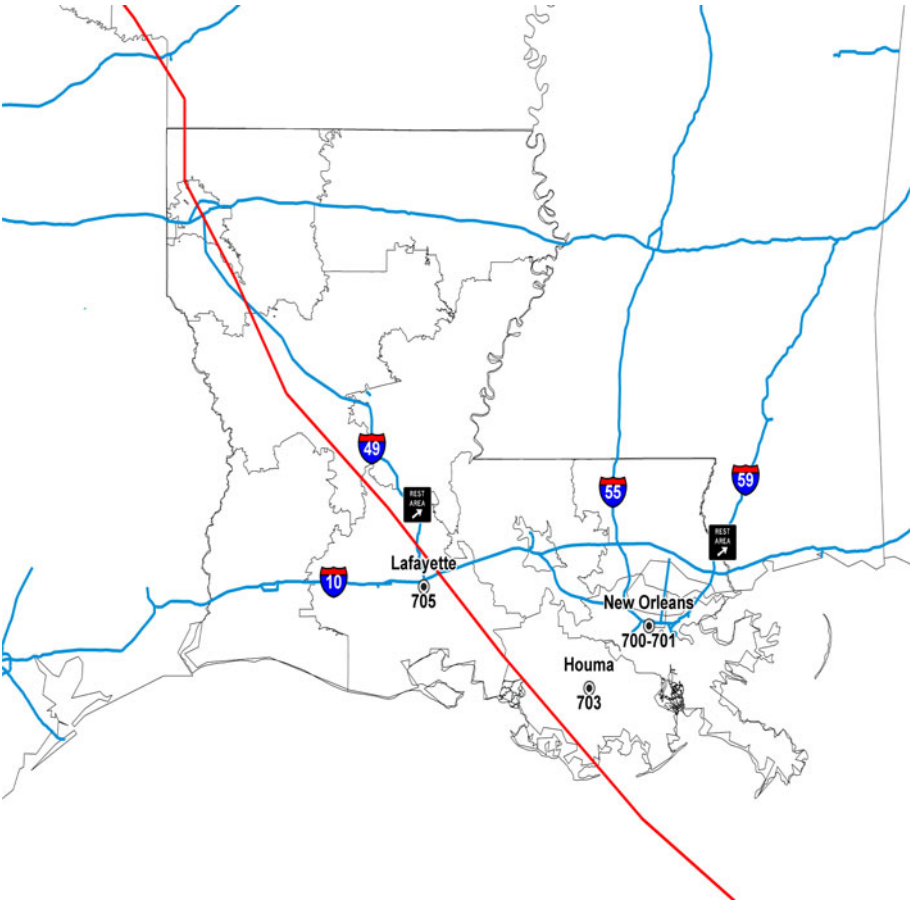

Fig. 1 Location of the three zip code regions represented in the analysis. The *red line* represents the official track of Hurricane Gustav; the *blue lines* represent interstate road networks with the two survey locations denoted by rest *stop symbols*; and the shields with numbers represent the interstate highway system in southern Louisiana

evacuees stopping at each rest stop were approached at random by a member of the survey team at various locations on the grounds of the rest stop, with every effort made to ensure only one member of a vehicle or caravan of vehicles was surveyed. In addition to the questions related to the meteorological hazards of Hurricane Gustav, evacuees were asked to include additional information which was used by Senkbeil et al. (2009) to assess the relationship between the perceived versus actual landfall of Hurricane Gustav. Evacuees were also asked to include their home zip code to geo-locate the survey participant's responses. Individual zip codes were not used since over 70 five-digit zip codes were represented and the number of responses by zip code did not allow for a thorough statistical analysis. As a result, individual five-digit zip codes were placed into regions based on the three-digit zip code prefix. The three primary regions included the New Orleans metropolitan area (zip code prefixes 700 and 701), the Lafayette region (prefix 703), and the Houma region (prefix 705). Evacuees completed a total of 275 surveys during the 2-day data collection period prior to the landfall of Hurricane Gustav.

Fig. 2 Evacuee traffic during survey process at the Interstate 49 rest stop in August 31, 2008. Photo taken near the end of the survey process, with fewer vehicles in rest stop

Survey respondents were asked to rank the meteorological hazards that most impacted their decision to evacuate (Fig. 3). The hazards included wind, storm surge, rainfall, tornadoes, and the spatial extent of the storm (noted as "storm size") and were ranked using a five-point Likert scale, with one (1) being the least important meteorological hazard and five (5) being the most important meteorological hazard in their evacuation decision. Responses were used to calculate an average raking for each meteorological variable from each three-digit zip code region and were also used to assess statistically significant differences in specific hazard threats between three-digit zip code regions. Thus, the analysis was performed descriptively for intra-region comparison and statistically for inter-region comparison.

The average rankings were used to analyze both intra- and inter-region variability among meteorological hazards from the dataset as a whole and from a random sample of 30 surveys within each zip code region. Similar to Senkbeil et al. (2009), 30 surveys were selected at random from the completed surveys in each three-digit zip code region. A random sample of 30 from each zip code region allowed for an analysis with equal group membership while removing any bias associated with a convenience sample. Random samples and total samples were then tested for significant differences to determine the association between the random and total samples. In order to facilitate inter-region comparisons between meteorological hazards, Mann–Whitney tests were used to determine statistically significant relationships. Specifically, Mann–Whitney tests were selected because of the ordinal and non-normally distributed survey response data.

3.2 Study area

The elevation of southern and coastal Louisiana varies from sea level along the Gulf of Mexico coastline to approximately 10 m above sea level in and around the city of

Please answer the following questions to the best of your ability:

How many years have you lived on the Gulf Coast? (If you do not live on the Gulf Coast, please state that you do not).

At what time and on what day did you make the decision to evacuate?

On a scale of 1-5 with 5 being the most important, please rank how important the following factors were in influencing your decision to evacuate:

	Least Important				Most Important
Wind	①	②	③	④	⑤
Storm Surge	①	②	③	④	⑤
Rainfall	①	②	③	④	⑤
Tornadoes	①	②	③	④	⑤
Size of the storm	①	②	③	④	⑤

How long (in number of hours) do you expect your home will experience hurricane conditions? (If you do not expect your home to experience hurricane conditions, please also state that.) _____ hours

How long do you expect to be away from your home?

Where (closest to what city) do you expect the hurricane to make landfall?

Was your decision to evacuate affected by Hurricane Katrina? If so, how?

On which of the following sources of information did you rely a great deal to help you decide to evacuate? (check all that apply)

□ A family member	□ A friend or neighbor
□ An official (e.g., police, fire dept., emergency management)	□ Other cable news channel such as Fox News, CNN or MSNBC
□ The Weather Channel	□ Local television station
□ Local radio station	□ The National Hurricane Center Website
□ Local National Weather Service website	□ Other Internet websites
□ Paging or instant messaging service	□ None—did not use any information
□ Other _____	

Was any one of the sources you checked more important than the others in your final decision to evacuate? (Which one)?

What is the zip code of your primary residence? _____

Does your household have any pets? □ Yes □ No

If yes, which of the following is true?
- □ Have all pets with you
- □ Left some or all pets at home
- □ Left pets with a boarding facility
- □ Left pets with a friend or relative

What type of pets do you have? □ Dog(s) □ Cat(s) □ Other(s)

Where do you expect your final evacuation destination to be?

Thank you very much for taking this survey! Have a safe trip.

Fig. 3 Sample of survey used during data collection

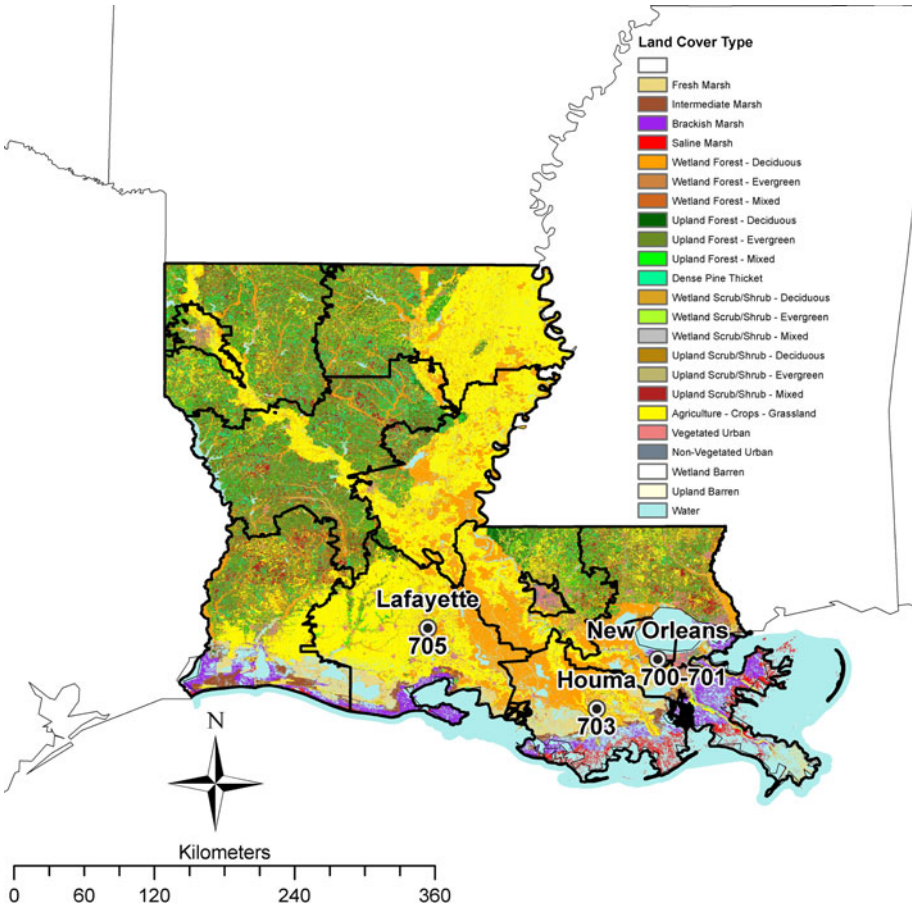

Fig. 4 Land cover type throughout Louisiana

Lafayette. Most of the region, however, is between 0 and 2 m above sea level. The greater New Orleans area (zip code 700/701), located on the south shore of Lake Pontchartrain, has the largest population in the region with approximately 1,300,000 residents. Suburban communities surrounding New Orleans are along higher-elevation meander scars and in areas protected by levees; whereas in rural areas of the 700/701 zip code region, the landscape is dominated by marshes and forested areas (Fig. 4).

Located in the south-central portion of the 703 zip code, Houma and Thibodaux are the most populous communities in the region (approximately 194,000 residents in the metropolitan area), where elevations of between 0 and 2 m above sea level are common. In the higher-elevation areas, soy, sugar cane, and corn are grown; however, most of the region is dominated by forests. Outside of Houma and Thibodaux, urban areas are located along sediment deposits flanking bayous and river channels, which is similar to the New Orleans metropolitan area. The Lafayette region (zip code 705) is primarily agricultural, with soy, sugar cane, corn, and rice cultivated here, with the eastern boundary of the region transitioning into forest. Lafayette's metropolitan population is approximately 240,000 and

is located in the central portion of the 705 zip code region. The elevation south of Lafayette is between 0 and 4 m and between 4 and 10 m from Lafayette north.

4 Results and discussion

Likert scale responses from evacuees were used to calculate average rankings for each of the five meteorological variables considered. Table 1 shows the total number of responses for each variable by three-digit zip code region. Initially, survey results from all participants were pooled together and used to calculate an average ranking for each hazard (Table 2). For the dataset as a whole, survey respondents ranked storm surge as the most significant meteorological hazard, followed by storm size, wind, rain, and tornadoes. Results were then separated into three-digit zip code regions representing the areas of New Orleans (700/701), Houma (703), and Lafayette (705). Within each zip code region, survey results were tabulated and used to calculate an average ranking for each of the five variables to compare intra- and inter-region variability. Additionally, 30 random surveys were selected from each three-digit zip code region to further evaluate intra- and inter-region variability.

4.1 Storm surge

Comparing all samples and random samples from each zip code region, evacuees from greater New Orleans area and from the Houma region ranked storm surge as the most important meteorological hazard they considered prior to evacuation (Fig. 5a). Evacuees from these regions appear to have observed the threat posed by storm surge, noting that the forecasted track of Gustav placed the New Orleans and Houma regions in the right-front quadrant of the hurricane, where the greatest storm surge damage potential typically exists (Rappaport 2000) (Fig. 6). Storm surge was generally less of a concern for residents in the Lafayette region. Respondents from the Lafayette zip code region ranked storm surge behind wind and the size of the storm. A large number of the zip codes represented within

Table 1 Total number of responses for each meteorological hazard for each three-digit zip code region

Zip code region	Wind	Storm surge	Rain	Tornado	Storm size
700/701	102	106	99	87	95
703	58	58	54	54	50
705	64	66	59	59	63

Table 2 Average ranking of each meteorological hazard from the dataset as a whole

Hurricane hazard	Average ranking
Storm surge	4.29
Storm size	3.95
Wind	3.90
Rain	3.64
Tornado	3.62

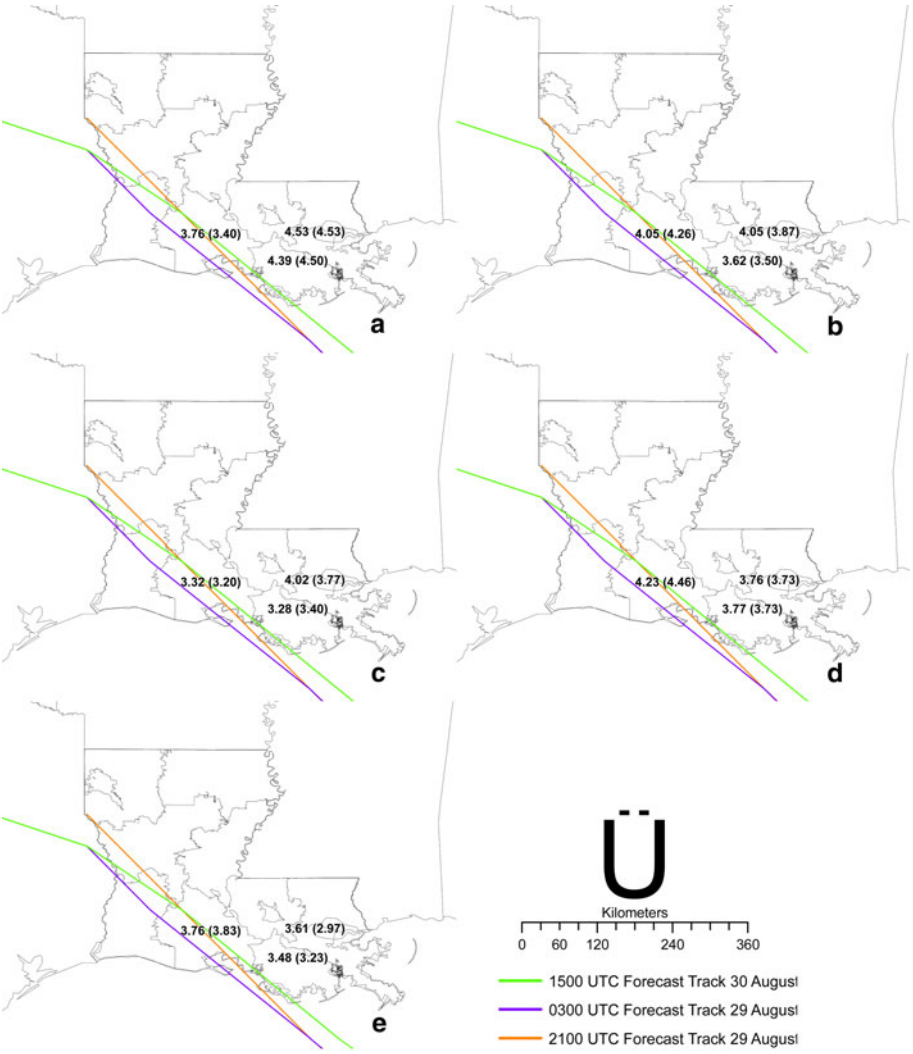

Fig. 5 Average ranking of the primary meteorological hazards evacuees considered in the decision to evacuate, separated by zip code region. Meteorological hazards are **a** storm surge, **b** storm size, **c** rain, **d** wind, and **e** tornadoes. The forecasted track of Hurricane Gustav is shown at the average time of evacuation decision, from Senkbeil et al. (2009). The *orange line* is at 4 p.m. CDT (2100 UTC) on August 29, the *purple line* is at 10 p.m. CDT (0300 UTC) on August 29, and the *green line* is at 10 a.m. CDT (1500 UTC) on August 30

the Lafayette region were from inland locations, which could be a reason why there was less concern over storm surge. Comments were also made during the survey process about Gustav's forecasted track placing the most significant storm surge probability east of Lafayette.

In many instances during the survey process, evacuees from the greater New Orleans area stated that their experience during and immediately after Hurricane Katrina in 2005,

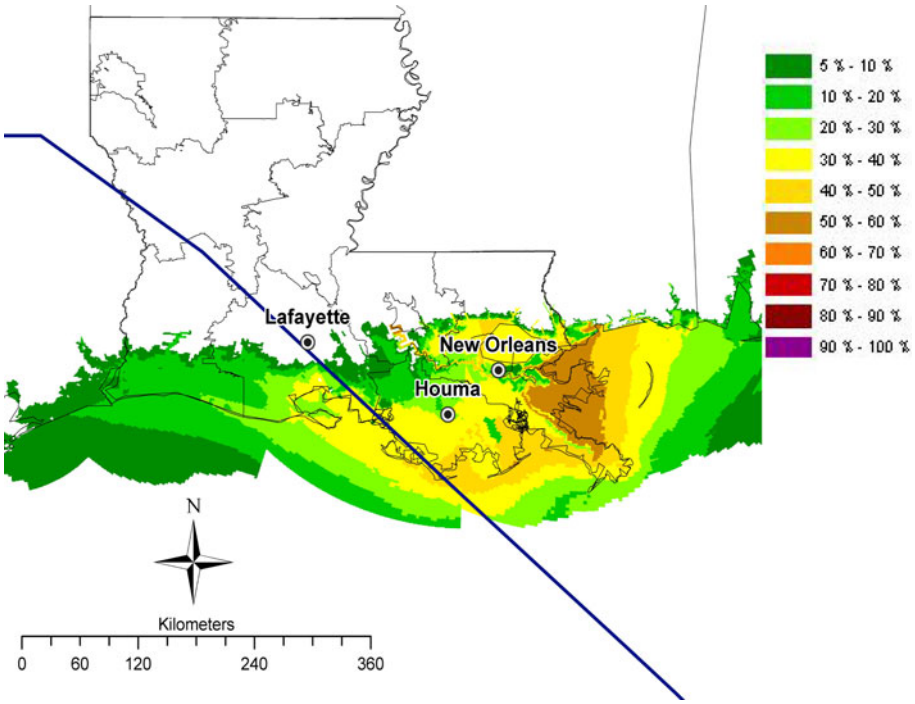

Fig. 6 Probabilistic storm surge forecast for coastal Louisiana valid from August 30 at 4 p.m. CDT (2100 UTC) to 2 September at 10 p.m. CDT (0300 UTC). *Colors* represent the percent chance of a storm surge greater than five feet. The *blue line* represents the track forecast at the same time as the issuance of the storm surge forecast

and the impact of storm surge in particular, was a factor in determining the proper time to evacuate. Similar to the results of Senkbeil et al. (2009), 83% of evacuees surveyed from the New Orleans region stated their decision to leave was influenced in part by their experience with Katrina. The impact of Katrina was less for evacuees from the Houma region, with 48% of participants stating Katrina factored into their evacuation decision. The difference between regions is likely a result of the major Katrina-related damage occurring well east of the Houma area. The impact of Katrina in the Lafayette region was less than the other two regions, with 38% of evacuees surveyed stating Katrina influenced their evacuation decision. Interestingly, approximately 20% of the respondents said previous experience with Hurricane Rita in 2005 and Hurricane Andrew in 1992 was more of a factor than experience with Hurricane Katrina, likely a result of hurricane passage directly over (with Andrew) or to the west (with Rita) of the Lafayette region. This may also be one of the reasons why, according to Senkbeil et al. (2009), the average time of evacuation decision was 63 h prior to landfall versus 45 h for Houma.

When comparing inter-region variability, a statistically significant difference between the ranked sums of storm surge was noted between New Orleans and Houma with Lafayette (Table 3) indicating that storm surge was not as significant of a hazard for residents of the Lafayette region when compared to those in the New Orleans and Houma regions. The Lafayette region generally has higher elevations, and it was forecasted to be on the western side of the storm, thus reducing the surge threat.

Table 3 Mann–Whitney tests between regions by meteorological hazard

Statistically significant pairs are shown with *P* values. Region of greater concern bolded

Meteorological hazard	Region pair	*P* value
Wind	**Lafayette**/New Orleans	0.012
Storm surge	**New Orleans**/Lafayette	0.000
Storm surge	**Houma**/Lafayette	0.013
Rain	**New Orleans**/Houma	0.001
Rain	**New Orleans**/Lafayette	0.002

4.2 Storm size

The mean ranking for the whole and the random sample resulted in storm size as the next meteorological hazard considered by evacuees from the greater New Orleans and Lafayette areas. The Houma region ranked storm size the third most important meteorological hazard (Fig. 5b). Inter-region comparisons did not show any statistically significant differences in storm size for the three regions. While not a measured variable like storm surge or wind, the size of the storm depicted by satellite imagery can have a significant influence on the perceived threat posed by the hurricane. Burnside et al. (2007) noted that images of a storm's prior damage can influence evacuee perception of what might occur if the hurricane were to make landfall again. Respondents from the New Orleans and Lafayette areas acknowledged that they were paying attention to the size of the storm, more so than evacuees from the Houma region, and were beginning to anticipate what conditions to expect when Gustav made landfall based on the size and appearance of the storm (Fig. 7). When asked about why they were or were not paying attention to storm size, residents from the Houma area had a sense that there was very little chance they would not be directly

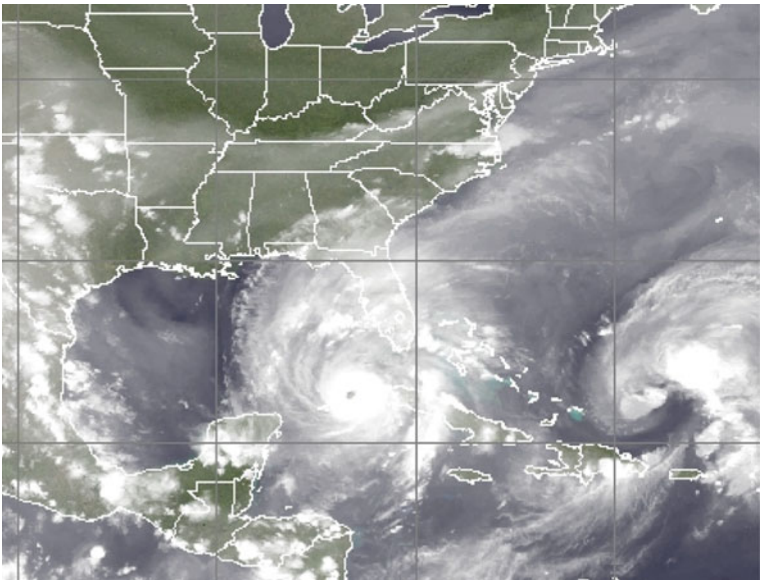

Fig. 7 Satellite image of Hurricane Gustav from August 30, 2008 at 1900 UTC. Image from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Source: http://tropic.ssec.wisc.edu/archive/

impacted by the hurricane, while evacuees in the New Orleans and Lafayette areas stated that any change in the forecasted track of Gustav would likely result in a change in the expected impacts on their homes and communities. As noted by Senkbeil et al. (2009) and Senkbeil and Sheridan (2006), a majority of evacuees reside outside the area of intense damage surrounding the hurricane eye and do not experience the worst of the storm. If the expectation of damage prior to landfall does occur, coastal residents may choose to change their evacuation behavior during future storms for better or worse. In order to gain insight into pre- and post-landfall perceptions of the damage and experience with Gustav, evacuees were directed to a voluntary, post-hurricane online survey to provide feedback; however, there were not enough responses for any analysis. Post-hurricane assessment is important to reconcile any remaining confusion between pre-landfall perception and post-landfall reality.

4.3 Wind

In the Lafayette region, evacuees ranked wind as the most significant meteorological hazard they considered during the evacuation decision process. In the Houma and New Orleans regions, the average ranking of wind placed this hazard second and fourth, respectively (Fig. 5c). Within each zip code region, there was not a significant difference between the random sample and the whole survey population. Additionally, Mann–Whitney tests revealed a statistically significant difference between the ranked sums of Lafayette and New Orleans (Table 3), highlighting the importance of wind in evacuation decisions for residents of the Lafayette zip code region.

We hypothesize that wind was a more significant hazard for the evacuees surveyed from the Lafayette zip code region because of the forecasted track of Gustav, their location of residence, and the more open agricultural and prairie landscape of this region. As was noted in Sect. 4.1, evacuees from the Lafayette region did not consider storm surge a significant threat because the anticipated track of Gustav kept the right-front quadrant east of the area. Additionally, evacuees from this region were from higher-elevation areas and were from inland locations. Wind may have been of greater concern to Lafayette-area residents because, relative to the New Orleans and Houma regions, the Lafayette zip code region is primarily agricultural, with areas of soy, sugar cane, corn, and rice, along with coastal marshes bordering the Gulf of Mexico. The only forested areas are on the zip code region's sparsely populated swampy eastern border. As a result, this region may be more exposed, and possibly more prone, to the effects of high winds. In numerous instances, the highest wind speeds associated with land-falling Louisiana hurricanes occurred within the Lafayette zip code region (e.g., Danny in 1984, Andrew in 1992, and Lili in 2002; from National Hurricane Center 2010). A small number of evacuees from rural locations within the Lafayette region also stated winds were a concern because of the exposure due to open agricultural land in the region.

4.4 Rainfall

Rainfall from Hurricane Gustav was the next meteorological hazard survey respondents from southern Louisiana ranked as influencing their decision to evacuate (Fig. 5d). Similar to storm surge and storm size, wind, and rain, there were no statistically significant differences between the whole sample and random samples within each zip code region. New Orleans area evacuees were more concerned about the threat from rain than evacuees from the Houma or Lafayette regions (Table 3). Through conversation with evacuees, the

concern over rainfall from Hurricane Gustav was primarily a result of the ever-present flooding danger within each of the three regions. In New Orleans, some evacuees mentioned levee failure and storm water pumps breaking down as a concern, while evacuees from the Houma and Lafayette areas talked more of standing water from heavy rains. Evacuees also noted that if large amounts of rainfall were to occur with Gustav, they expected to be kept away from their homes longer because of the challenges removing water from the metropolitan areas or from impassable roadways. There was a sense that evacuees were less concerned about rainfall because flooding is a recurring issue at different times throughout the year and were prepared for any possible flooding as a result.

4.5 Tornadoes

The threat from tornadoes was determined to be the least important meteorological variable considered during evacuation, as seen in Fig. 5e. Tornado occurrences are common with land-falling hurricanes (e.g., Baker et al. 2009) as a result of the unique atmospheric dynamics present within the rainbands of the storm. In a majority of instances, tornadogenesis is most frequent in the right-front quadrant of the hurricane (McCaul 1991), but can also occur in regions where local-scale atmospheric boundaries promote the rapid formation of tornadoes (Edwards and Pietrycha 2006). While persistently a threat during land fall of a hurricane such as Gustav, the threat is typically less of a concern, and in some cases considered a by-product of the actual storm. For each of the three-digit zip code regions, tornadoes were not considered a significant meteorological hazard influencing evacuation.

5 Summary and conclusions

Hurricane Gustav presented a unique opportunity to survey evacuees in the path of the storm prior to landfall. These time-sensitive data were to evaluate which meteorological hazards they considered most important in their decision to evacuate. During a 2-day period prior to landfall (August 30 and 31, 2008), surveys were distributed to evacuees at interstate rest stops along two major evacuation routes for southern and coastal Louisiana. A total of 275 surveys were completed during the field project, focusing primarily on understanding the evacuee's perception of risk from the meteorological components of Gustav. To the author's knowledge, this is the first attempt at collecting perceived meteorological hazard data from evacuees prior to landfall during the evacuation process.

Survey respondents ranked five meteorological variables (wind, storm surge, rain, tornadoes, and the size of the storm) on a five-point Likert scale to determine which meteorological elements related to Hurricane Gustav were most significant in their evacuation decision. Zip code data were used to place evacuee responses into three-digit zip code regions, with the areas of New Orleans (700/701), Houma (703), and Lafayette (705) represented most frequently. In each zip code region, average rankings were calculated for each of the meteorological variables considered for all responses and for a random sample of 30 surveys. From these results, comparisons between regions and within regions were made.

When separated into three-digit zip code regions, intra-region results revealed the following:

- Evacuees from the New Orleans metropolitan region (700/701 zip codes) ranked storm surge and the size of the storm as the most important meteorological hazards associated with Hurricane Gustav and the biggest factor in their decision to evacuate. A total of 83% of evacuees from this region cited previous experience with Hurricane Katrina as a major factor in determining what they considered the most significant meteorological threat from Gustav. Evacuees of the New Orleans region ranked rain, wind, and tornadoes next in descending order of importance.
- Survey respondents from the Houma region (zip code 703) considered storm surge as the most important meteorological element influencing their decision to leave. For residents of this region, the experience from Katrina did not play as significant a role in the evaluation of threats from Gustav, but rather the forecast track of Gustav placing them in the right-front quadrant of the hurricane, where storm surge is a significant threat. The average ranking by evacuees placed wind as the next meteorological variable they considered, followed by storm size, tornadoes, and rain.
- Evacuees from the Lafayette region (zip code 705) ranked wind as the most significant meteorological variable in their evacuation decision, followed by the size of the storm, storm surge, the threat of tornadoes, and rain. The concern over wind in the Lafayette region was a result of the physiographic environment of the area. The 705 zip code region is primarily prairie and cultivated crops, with limited stand of trees to act as a buffer from the tropical storm and hurricane-force winds. Previous hurricane experiences of the residents of this region have prepared them to anticipate wind as the most significant variable. The southeast to northwest track of Gustav led evacuees to believe the Lafayette region would receive less of an impact from storm surge than the Houma or New Orleans areas.

When comparing inter-region variability, Mann–Whitney tests were used to evaluate the statistically significant relationships between meteorological hazards. Inter-region comparisons revealed:

- There was a statistically significant difference noted in the average ranking of storm surge between the New Orleans and Houma regions with the Lafayette region, likely due to the southeast to northwest forecast track of Gustav and the larger number of inland evacuees from the Lafayette region.
- A statistically significant difference in the average ranking of rain was noted between New Orleans with Houma and Lafayette. Evacuees from the New Orleans area stated that even though rain was not their first concern when considering the meteorological hazards associated with Hurricane Gustav, they were worried about the potential flooding. Houma and Lafayette evacuees were less worried about rain and flooding threats.
- There was a statistically significant difference in the ranking of wind between Lafayette and New Orleans. Evacuees from the Lafayette region mentioned their concern over the threat from tropical storm and hurricane-force winds was primarily a result of previous experience with hurricanes in the region.

The results from this study address two areas where data collection and analyses have been limited: understanding how the meteorological hazards associated with a land-falling hurricane may influence evacuation decisions and surveying evacuees prior to the landfall of a hurricane, during the evacuation process. Future research will attempt to collect data from other areas along the Gulf and Atlantic coasts and to survey additional affected

populations, including hurricane shelters and those who choose not to leave, to better understand hurricane hazards perception and how it relates to evacuation decision making.

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